東北大学機関リポジトリ
TOUR
Tohoku University Repository

Automated Detection of Pre-stimulus HR Level Suitable for Presenting Painful Electric Stimulation

著者	YAMAGUCHI HIROSHI, HATAYAMA TOSHITERU, OHYAMA MASAHIRO
journal or publication title	Tohoku psychologica folia
volume	41
page range	54-63
year	1983-03-22
URL	http://hdl.handle.net/10097/62942

Tohoku Psychologica Folia
1982, 41 (1-4), 54-63

AUTOMATED DETECTION OF PRE-STIMULUS HR LEVEL SUITABLE FOR PRESENTING PAINFUL ELECTRIC STIMULATION

By

HIROSHI YAMAGUCHI (山口 浩)[1],
TOSHITERU HATAYAMA (畑山俊輝)[1]
and
MASAHIRO OHYAMA (大山正博)[2]

(*Tohoku University*)

An improved technique was reported for microcomputer controlled stimulus presentation under aversive situation and for on-line processing of acquired data. The phsical states of subject, determined by autonomic and somatic measures were monitored to detect the timing of aversive stimulus presentation. It was at the time of physical states, pre-determined by experimental condition, with relative steadiness that the electric stimulation was delivered to a right forearm. Concerning data analysis, heart rate (HR) data was, on-line, processed to execute beat-by-beat analysis, removing fluctuation of ECG baseline. A representative case was demonstrated of HR change before and after shock presentation, and this instrumentation was evaluated.

Many psychophysiological studies on motivational-affective aspects of pain, merely reported various physiological changes from the time before to the time after the presentation of aversive stimulus. Namely, strictly speaking, the psychological and physiological states of subject immediately before the presentation of aversive stimulus were largely changeable in every experimental trial, and consequently, the states after aversive stimulus would be also varied across the trials and subjects. This situation has made it difficult to point out what kinds of psychophysiological indicants were correlated with pain experience. It was thought very important that psychological and physiological states were relatively kept constant before presentation of noxious stimulus, in order to study the psychophysiological, or the affective-emotional aspects of pain. Studies along these lines were done (Hatayama, Ohyama, & Yamaguchi, 1980; Yamaguchi, Hayatama, & Ohyama, 1981).

This paper was aimed at examining the effectivity of new techniques for presenting noxious stimulation, and the reduction of related data. In the present paper, the experimental procedure was planned to monitor the state of subject immediately before presentation of noxious stimulus. The procedure involved the followings.

1. Department of Psychology, Faculty of Arts and Letters, Tohoku University, Kawauchi, Sendai 980, Japan.
2. College of Medical Sciences, Tohoku University, Seiryocho, Sendai 980, Japan.

(1) The HR level was kept below a certain level predetermined.

(2) The EMG level from the right forearm on which an electric shock stimulus was presented, was kept in a certain range of muscle tention.

(3) The respiration cycle was in either inspiration or expiration one, due to experimental condition.

When these conditions were all satisfied, a noxious stimulus was presented.

In data analysis of HR, considered an important autonomic measure of affective aspects of pain, we particularly took into account:

(1) Removing the fluctuation of ECG baseline, to make the detection of R wave easier and more certain.

(2) Analyzing, on-line, instantaneous successive HR data before and after the presentation of aversive stimulus.

In the present paper, some experimental techniques about the above-mentioned were reproted in detail, which were thought to be useful to carry out the studies on relationship between emotion and its physiological correlates, as well as on experimental pain.

Method

In this experiment, two microcomputers were used. One (TK–80 BS) was used as the controller of experiment, and the other (MZ–80B) was used as the on-line data analyzer. The explanation about the Method was devided into two sections of *Hardware* and *Software*.

Hardware

Fig. 1 represents the systematic block diagram of this experiment. The EMG from the muscle of the right forearm, HR from the electrodes across the chest were measured. Respiration was recorded from the respiration strain gauge of rubber tube wound with a belt around the abdomen. All measures were preamplified by a Nihon Koden AB–620G, and recorded on magnetic tape by a Sony NFR–3515 type recorder. Further, Fig. 1 was explained in parts of (1) apparatus for presenting feedback tone based on EMG from the right forearm, (2) apparatus for measuring HR, (3) apparatus for detecting either inspiration or expiration of respiration cycle.

(1) *Apparatus for presenting feedback tone based on EMG.*

*S*s were required to maintain the right-forearm muscle tention in a certain range predetermined (i.e. hereinafter referred to as reference range). This reference range was between 260 μV and 610 μV. Subject was seated in a comfortable armchair in an electrically shielded, dimly lit and sound-proof room. *S*s kept his EMG in reference range by means of pulling the fixed expander in front of a right armrest of armchair, and by receiving EMG feedback tone (1k Hz, 59 dB). The EMG preamplified was rectified and integrated by a Nihon Koden EI–600G, and this signal enter a

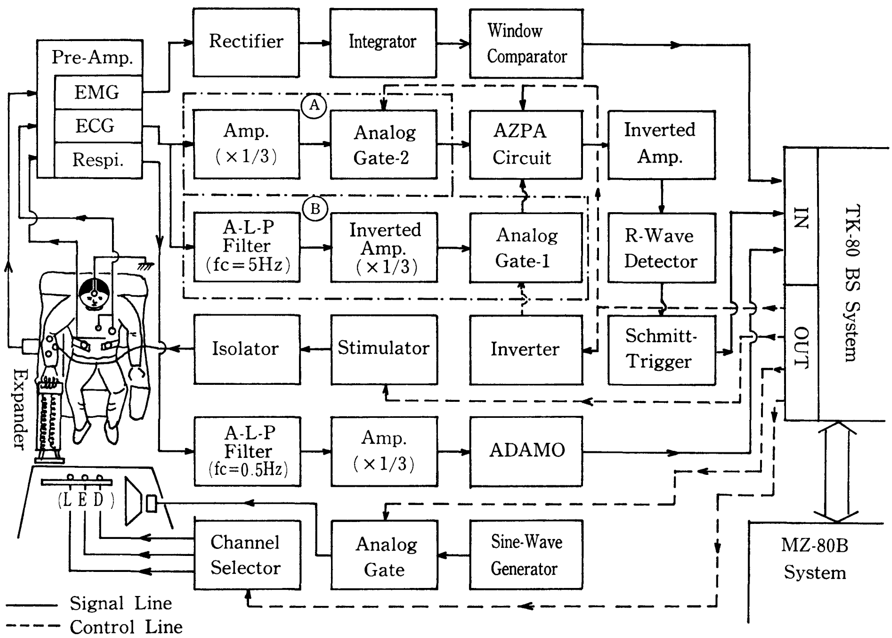

Fig. 1. Systematic block diagram of this experiment. Abbreviations: AZPA Circuit= Auto-zero-point-adjuster circuit; A-L-P Filter=Active low pass filter; ADAMO=A/D status converter module.

window comparator of a Nihon Koden EN-601J. This window comparator was adjusted to generate low TTL level when EMG was within reference range. This signal which controlled the analog gate next to a 1k Hz sine-wave generator, consequently produced the tone only when EMG was outside the reference range. Further, signals from the window comparator were detected by two microcomputers.

(2) *Apparatus for measuring HR.*

In this experiment, R waves in ECG were detected and counted by microcomputer of controller. Further, instantaneous HR was measured, on-line, by microcomputer of data analyzer, which read the time between successive R-R waves at sampling time of 5 msec.

In our previous reports (Hatayama et al., 1980; Yamaguchi et al., 1981), HR data were analyzed, off-line, by microcomputer from the magnetic tape. But it was occasionally difficult to detect R wave, when ECG baseline shifted largely, which often appeared immediately after the presentation of electric shock stimulus, in paticular subjects. In order to solve this difficulty, in this experiment a new apparatus was contrived, as will be described in detail as follows.

The ECG preamplified entered the (A) and the (B) circuits as shown in Fig. 1. The (A) circuit for detecting the shift of ECG baseline consisted of an active low pass filter (cut-off frequency of 5 Hz), an inverted amplifier, and an analog-gate-1. The (B) circuit for matching the output range to the (A) circuit consisted of an amplifier and an analog-gate-2. A control signal (27 msec duration, in this experiment) from the microcomputer was transported to the analog-gate-2 and the analog-gate-1 through an inverter. And so, the input signal to the 'Auto-zero-point-adjuster circuit' (AZPA circuit) was alternate between the output from (A) circuit and the output from (B) one. The AZPA circuit consisted of Digital Servo Module (DISMO-8AP XEBEC Co., Ltd.)[3] and an OP amplifier. A control signal from the microcomputer to the DISMO was the same as the control signal to the analog-gate-2 and to the inverter connected to analog-gate-1. When this control signal was in high level, DISMO was in "tracking condition" to the input signal, in which condition the AZPA circuit operted as negative feedback one. In that condition, its output was held in the zero voltage. Next, when the control signal was exchanged for the signal in low level, the DISMO was in "holding condition", the DISMO memorized and held the voltage of input at the time of the foregoing tracking period immediately before this holding one, and consistently subtracted this voltage from the ongoing input one. So the AZPA circuit produced the ongoing difference voltage.

In this experiment, the control signals from microcomputer to analog-gate-2 and DISMO, and to analog-gate-1 through inverter were discharged at the time of 216.5 msec or 217.7 msec directly after the detection of each R wave according to the software for an experiment. When the control signal was in high level, the output signal from the (A) circuit was transported into the AZPA circuit. Namely, the DISMO was tracking the ECG baseline for 27 msec immediately before a T wave coming. When the control signal was exchanged for low level, the input signal to the AZPA circuit was alternated with the output from the (B) circuit, and DISMO was in holding and subtracting condition. Namely, the output from AZPA circuit was the ECG obtained by subtracting the voltage of ECG baseline from the ECG signal just preamplified. The ECG baseline had been measured in the tracking period directly before holding one. This ECG was transported into the R-wave-detector and the shmitt-trigger circuit through the inverted amplifier. The shmitt-trigger circuit, which transformed R wave into square one, was connected to both the microcomputers of controller and the data-analyzer. Consequently, the R wave was detected easily and certainly in the condition of substantially cutting off the shift of the ECG baseline.

(3) *Apparatus for detecting inspiration or expiration of the respiration cycle.*

The respiration signal preamplified was transported to the A/D status converter module (ADAMO, AE-004L, by Accord Electronics Co., Ltd.)[4], through an active low pass filter with cut-off frequency of 0.5 Hz and an amplifier. The output from the ADAMO was the TTL logical signal flip-flopped at the point of inflection in the

3. Xebec Co., Ltd. Kasuya 4-21-12, Setagaya-ku, Tokyo, 157 Japan.
4. Accord Electronics Co., Ltd. Oyama-machi 3144, Machida, Tokyo, 194-02 Japan.

sinuous signal of respiration cycle. The ADAMO has two output terminals of Q and $\overline{Q}$. The inspiration cycle was detected from the output Q and the expiration from $\overline{Q}$. This signal was transported to the microcomputer of controller.

Software

The two kinds of software are briefly explained in the followings. One was for TK-80BS of controller, the other was for MZ-80B of on-line data analyzer.

(1) *Experimental program for TK-80BS*

(a) *main routine in BASIC*: This program was for the experimental period. After "initializing", a reference-HR-value was determined by the experimenter as the reference level, based on which subject's HR-level was kept in relatively low and constant range before shock presentation. The reference-HR-value was ordinarily 75 bpm. Next, the program jumped to the subroutine in the machine language. After the completion of subroutine, the program returned to the main routine, and displayed various information about a just finished trial. If all experimental trials were finished, the program ended, but if not, it executed next experimental trial.

(b) *subroutine in the machine language*: In this subroutine the microcomputer took in various input signals and gave out some control ones. The flowchart in Fig. 2 represents the subroutine in the machine language. After "initializing" and "on" of data recorder and pen recorder, the computer began to count R waves. The porgram was not allowed to proceed until the subject's HR-level satisfied the condition that his HRs were kept within three beats above the pre-determined reference-HR-value in successive twelve heart beats. Namely, the program was waiting for the subject to calm himself.

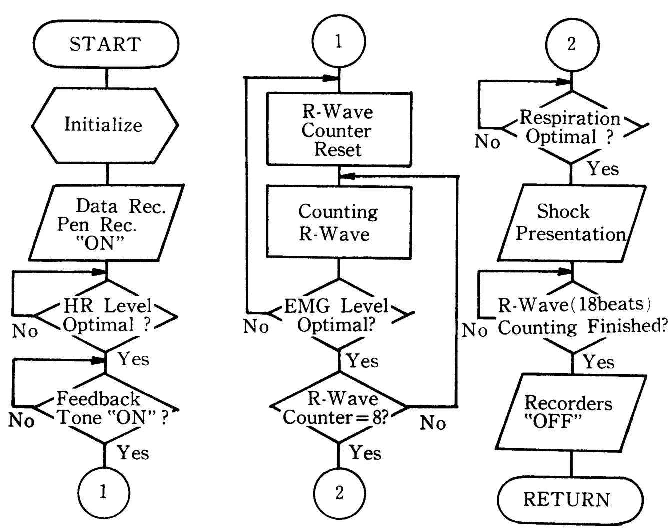

Fig. 2. Flowchart of machine-subroutine in experimental program

After that, the computer began to detect signal from the window comparator. In other words, it began to check if the feedback tone was sounded or not. If the tone was not spontaneously sounded, the experimenter made subject sound it by instruction through interphone by means of deviating muscle tension level from the reference EMG level. After presentation of feedback tone, R waves were counted by 8 heart beats in the condition of keeping EMG within the reference range. After the completion of counting heart beats, the computer began to check the output from the ADAMO and R waves. After that, an electric shock stimulus on the subject's right forearm was triggered by the first R wave which was in the respiration predetermined due to the experimental condition (either inspiration or expiration). Before the shock presentation, however, if EMG level deviated from the reference range (i.e. if the feedback tone sounded), R waves were counted again from the first by eight beats. After shock presentation R waves were counted by 18 beats. By the completion of counting, the data recorder and pen recorder were stopped. The execution of program was returned to the main routine.

In this experiment, three time periods were defined within each trial as follows. The foreperiod was defined as the period from the time of the last finish of the feedback tone to the time of the presentation of shock stimulus. The pre-foreperiod was the period that consisted of 12 cardiac cycles immediately before the foreperiod. The after-shock period consisted of 18 cardiac cycles after shock.

(2) *Program for on-line data analyses.*

The following description of the on-line analysis program was devided into two: a main routine in BASIC and a subroutine in machine language for acquiring HR data.

(a) *main routine in BASIC*: This BASIC main routine consisted of five blocks. The first and the third were for the processing of HR data acquired in pre- and post-experimental resting periods respectively. The purpose of these analyses was the determination of two mean HR values, which values were called the Pre-mean-HR and the Post-mean-HR. In these blocks, the time between successive R-R waves was read so far as 200 cardiac cycles in the machine-subroutine and each cardiac cycle was converted into heart rate (bpm). The 200 HRs were sorted in order of lower HR, and were stored in the cassette tape. After that, the Pre-mean-HR (or Post-mean-HR) and the *SD* were calculated from 120 HRs which were the remainder after both 20% ends of all in the distribution of HRs were eliminated. After the completion of this calculation, Pre-mean-HR (or Post-mean-HR), *SD* and all HR data in the resting period were displayed on a green monitor and were printed out on a line-printer.

The second block in the main routine was for the processing of HR data in each experimental trial. Data acquisition was done in the machine-subroutine which was described later on. In each experimental trial, the microcomputer calculated the mean HR of the last 10 HRs in the pre-foreperiod, and produced the difference scores (bpm) obtained by subtracting the mean HR from the successive HRs during the foreperiod and the after-shock period. Until the experimental period finished, the computer executed these kinds of calculation, made the data files in the cassette tape and displayed data and graph in every experimental trial.

The fourth block was off-line analysis for the determining the mean HR value in all resting periods that involved pre- and post-resting ones. The computer read all of HR data in the resting periods from the cassette data files, and sorted all HR data (400 HRs) in order of lower HR. In the same way as in analysis at the first and third blocks, both 20% ends were cut off from the distribution of HRs. After that, the Whole-mean-HR and *SD* were calculated from the remainder of 240 HR data.

The fifth block was for off-line analysis of HR data in each experimental trial by using the whole-mean-HR. It was in the same way as in the second block analysis mentioned above except using the Whole-mean-HR. The HR data were read from cassette data filed after the experimental period. The microcomputer calculated the difference scores (bpm) obtained by subtracting the Whole-mean-HR from the successive HRs during the foreperiod and the after-shock period in each experimental trial.

The reason for carrying out this analysis was as follows. In this experiment, the experimental program was not allowed to proceed until the subject's HR-level satisfied the condition predetermined. By this procedure, relatively low and constant HR levels were acquired in the pre-foreperiod through each trial. But still, there was some possibility of the mean HRs in the pre-foreperiods being different through each experimental trial. So, from the viewpoint of the "law of initial value", it was insufficient for studying a changing pattern of HRs to use the only difference scores from the mean HR taken at each pre-foreperiod in each trial. We also need a difference score from a certain constant value through all trials for comparing all trial data at the same time. In our analysis, a Whole-mean-HR as explained above was used as the constant value and the difference scores were calculated in every trial based on the Whole-mean-HR, during the foreperiod and after-shock period.

(b) *subroutine in the machine language*: This subroutine was for instantaneous HR data acquisition both in the pre- and post-resting periods and experimental period. The start and the end of this program were controlled by a manual start-or-end key in the resting periods, and were controlled by start- and end-signals from the TK–80BS of controller in the experimental period. In the resting periods, this program simply acquired the time between successive R-R waves at sampling time of 5 msec. In the experimental period, after the first R wave came, the microcomputer read the cardiac cycle and checked a shock-signal, signals from window comparator, and a next R wave coming. Every time when the output from the window comparator was "off" in the foreperiod, the microcomputer rememorized the address of data of the last cardiac cycle during the output "off" until it was "on", before shock presentation. Namely, the computer finally stored the data address of the cardiac cycle at the time when the latest feedback tone was "off" in the foreperiod. The data address of the cardiac cycle at the shock presentation was also stored in the memory. These addresses were necessary for the analysis of each experimental trial, which was done at the second and the fifth block in BASIC main routine, as above-mentioned.

The experiment was made with four subjects for two days. As mentioned before, the computer program for this experiment was not allowed to proceed until the subject's HR-level was kept in relatively low and constant range in pre-foreperiod. The mean HR levels obtained by this procedure were of 66.95 (bpm) for the first day, 67.51 for the second day, and *SD* of 5.78 for the first, 6.14 for the second in preforeperiod.

The recordings in Fig. 3-A, taken from a 6-channel pen recorder, were those from Subject E.M. These were recorded in experimental condition of high-EMG (with pulling expander) and 9 mA-shock triggered in inspiration. These six channels were as follows; Channel 1 for ECG taken from the output of "Auto-zero-point-adjuster circuit"; chan. 2 for respiration; chan. 3 for control signal to the DISMO emitted by a computer, which was triggered with R wave except the time just prior to the foreperiod; chan. 4 for EMG from the right forearm; chan. 5 for the output of the window comparator, with its "off-level" turning on the feedback tone; and chan. 6 for the marker of shock presentation.

These recordings were processed, on-line, as described in the second block of BASIC main routine in the data analysis program (Fig. 3-B). Twelve heart rate values (bpm) immediately before the latest "off" of the feedback tone were printed out

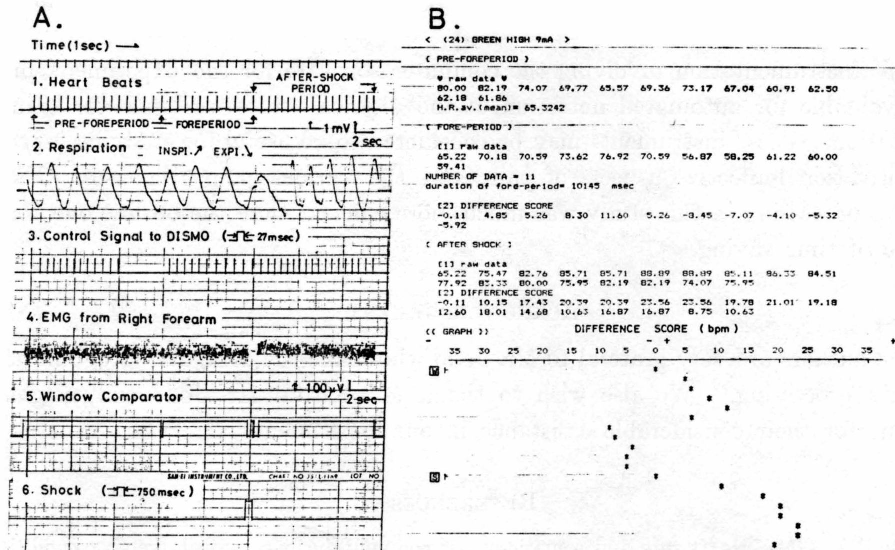

Fig. 3. A: an example of the recordings in experimental condition of high-EMG and 9mA-shock triggered in inspiration. B: the results of on-line data analysis of the recordings in Fig. 3. A.

together with mean HR of the last 10 HRs at the part of {PRE-FOREPERIOD}. Subsequent to this part, successive HR data were listed of foreperiod followed by presenting a shock stimulus. The foreperiod lasted for 10145 msec in the case of Fig. 3-B. Next part was for difference scores obtained by subtracting the mean HR in pre-foreperiod (65.32 bpm) from each successive HR value in the foreperiod. Likewise, 18 heart rate values and the corresponding difference scores were printed out at the {AFTER-SHOCK}. The {{GRAPH}} illustrated those difference scores (bpm) by asterisks in the foreperiod and the after-shock period. The beginnings of both foreperiod and after-shock period were marked by the symbols, "$\boxed{W}\vdash$" and "$\boxed{S}\vdash$". As shown in the {{GRAPH}}, heart rate changes were polyphasic before and after presenting shock. The HR change pattern in the foreperiod was characterized by acceleration accompanied with deceleration, and the presentation of shock caused a marked acceleration in the after-shock period. This HR change pattern was much the same as that reported in studies of HR changes under acute stress in humans (e.g., Hastings & Obrist, 1967; Obrist, 1968; Obrist, 1976).

This instrumentation for HR data analysis was hardly affected by the fluctuation of ECG baseline for detecting R wave, which was due to the "Auto-zero-point-adjuster circuit" considerably removing that fluctuation.

There was the possibility that the duration of foreperiod would be various in experimental trials, because the shock stimulus was triggered by the first R wave which was in the respiration cycle predetermined after the computer counted 8 beats in the foreperiod. But, not so many differences were found among the foreperiods, as the results revealed that the mean time of duration was of 8750.2 msec for the first day, 9026.0 msec for the second day, and *SD* of 1137.6 msec for the first day, 1379.4 msec for the second.

This instrumentation involving the computer software for the experiment proved to be valuable for automated detection of the physical state suitable for stimulus presentation. These instruments may be considered to be useful for studying especially the motivational-affective aspects of pain, and the various pain responses. The on-line data processing in this study was much more efficient than the off-line one for the purpose of time saving.

Acknowledgement

The authors are very grateful to Mr. Jodo who made the computer program of on-line data processing. We also wish to thank Mr. Kirita, Mr. Jodo and neighborly colleague for their considerable assistance in our experiment.

References

Obrist, P.A. **1968** Heart rate and somatic-motor coupling during classical aversive conditioning in humans. *Journal of Experimental Psychology*. **77**, 180–193.

Obrist, P.A. **1976** The cardiovascular-behavioral interaction — as it appears today. *Psychophysiology*. **13**, 95–107.

Hastings, S.E. & Obrist, P.A. **1967** Heart rate during conditioning in humans: effect of varying the interstimulus (CS-UCS) interval. *Journal of Experimental Psychology*. **74**, 431–442.

Hatayama, T., Ohyama, M., & Yamaguchi, H. **1980** Modification of pain sensation under EMG biofeedback controlled condition of muscle tension in forearm. *Tohoku Psychologica Folia*, **39** (**1-4**), 1–9.

Yamaguchi, H., Hatayama, T., & Ohyama, M. **1981** Affective-meotional aspects of experimntal pain. *Tohoku Psychologica Folia*. **40** (**1–4**), 110–121.

(Received November 15, 1982)